SOLAR EXERGY MAP OF TURKEY

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ABSTRACT

This study present the solar exergy map of Turkey has developed. Both thermal and electrical examples have been made for how the solar exergy map is implemented and for solar energy applications. Based on the exergy of solar radiation, the efficiency of photovoltaic systems for electrical production and Linear Fresnel reflector (LFR) systems for thermal power generation is examined in Turkey's climatic conditions. In the study, four different cities are investigated. In the study, solar exergy efficiency is calculated for seven different cities, Isparta, Bursa, İzmir, Sinop, Ankara, Iğdır and Şanlıurfa. As a result of the calculations, the efficiency of solar eclipse for Isparta, Bursa, İzmir, Sinop, Ankara, Iğdır and Şanlıurfa was found to be 12.91%, 12.92%, 11.65 %, 14.48%, 13.09%, 12.27% and 10.21% respectively.

1. INTRODUCTION

Solar energy has become an increasingly renewable source of energy in recent years. Research and technological developments have shown that the efficiency of Photovoltaic (PV) solar power systems will provide a promising increase in the coming years. PV systems, as well as systems that produce thermal energy from solar energy are developing rapidly.

The works focusing on solar energy technologies are as follows; improving the efficiency of PV systems, improving the efficiency of concentrated solar energy systems, solar-powered hydrogen generation, solar energy based hybrid systems, zero-energy sustainable or green buildings, solar energy-based thermal storage systems [1,2,3].

In this study, the thermal energy LFR was obtained. The linear Fresnel collector can be imagined as a broken-up parabolic trough reflector, but unlike parabolic troughs, the individual strips need not be of parabolic shape. The strips can also be mounted on flat field and concentrate light on a linear fixed receiver mounted on a tower [4]. The linear Fresnel reflector (LFR) allows the production of thermal energy at medium and high temperatures relative to the climate zone. LFR is widely used for simple production, easy maintenance and low cost advantage and thermal power generation systems [5,6].

In this work, to create a solar exergy map based on the solar radiation values. The creation of a solar exergy map will give more realistic results to solar energy applications for regions. It can also help investors, besides researchers, reduce economic losses. According to the report, which was prepared by the European Commission in 2016, the mapping energy priorities under the framework of the smart specialisation concept may help policy makers to define actions plans as well as maximize the impact of available resources [7].

Joshi et al. [8] have prepared a solar exergy map using PV/T solar power system in India and the United States. They have done this study for one year in different cities of India and USA. As a result, the highest exergy rate for India was 36% and the highest exergy rate for USA was 32.5%. Arslanoglu [9] have investigated three different empirical model for estimating the monthly average daily global solar radiation exergy on a horizontal surface for some provinces in different regions of Turkey. As a result, it have found an average value of solar exergy is 0.93 for Turkey. By Schibuola [10] in this research, it is aimed to integrate additional technical aspects into the solar maps with the help of reliability diagrams that can be used to evaluate potential electricity generation.

This main aim of the present paper is to develop the concept of a new emerging solar exergy map. In this context, Turkey's for 7 different cities such as Isparta, Bursa, Izmir, Sinop, Ankara, Iğdir and Şanlıurfa, solar exergy concept maps were developed. In these cities, both thermal energy and electric energy were investigated in solar exergy study.

2. THERMODYNAMIC ANALYSES

In this section have investigated the thermodynamic behaviour of the systems. However to determine the amount of thermal energy that is wasted the respective calculations were performed for the inlet and outlet exergy, mass flow rate, solar radiation and temperature. For the calculation of these equations, EES program is used for parametric studies and graphical drawings. Input solar radiation rate is found by;

$$\dot{En}_{solar} = I * \rho_{ref} * \rho_{rec} * \varepsilon_{rec} * A_{ref} * A_n * A_{rec} \quad (1)$$

Where I, ρ_{ref}, ρ_{rec}, ε_{rec}, A_{ref}, A_n are solar radiation, reflectance of the mirror, absorber of the receiver, emissivity of the receiver, reflector area, reflector numbers and receiver area, respectively.

$$\dot{En}_{solar} = \dot{m} * c_p * (T_{out} - T_{in}) \quad (2)$$

Where $\dot{m}$, c_p, T_{out} and T_{in} are mass flow of water, specific heat of water, temperature of output water and temperature of input water, respectively.

$$\dot{Ex}_{water} = \dot{Ex}_{out} - \dot{Ex}_{in} \quad (3)$$

Where $\dot{Ex}_{water}$, $\dot{Ex}_{out}$ and $\dot{Ex}_{in}$ are water exergy change, exergy of output water and exergy of input water, respectively.

$$\dot{Ex}_{out} = \dot{m} * c_p * \left[(T_{out} - T_{air}) - T_{air}\left(\ln\left(\frac{T_{out}}{T_{air}}\right)\right)\right] \quad (4)$$

Where T_{out} and T_{air} are temperature of output water and ambient temperature, respectively.

$$\dot{Ex}_{in} = \dot{m} * c_p * \left[(T_{in} - T_{air}) - T_{air}\left(\ln\left(\frac{T_{in}}{T_{air}}\right)\right)\right] \quad (5)$$

Where T_{in} is temperature of input water. Input solar radiation exergy rate is found by;

$$\dot{Ex}_{solar} = \dot{En}_{solar}\left(1 + \frac{1}{3}\left(\frac{T_{air}}{T_{sun}}\right)^4 - \frac{4}{3}\left(\frac{T_{air}}{T_{sun}}\right)\right) \quad (6)$$

Where T_{sun} is sun temperature. Electrical power output for PV systems can be found by;

$$\dot{Ex}_e = FFV_{oc}I_{sc} \quad (7)$$

Where FF, V_{oc}, I_{sc} are fill factory, the open circuit voltage and short circuit current, respectively. Exergy efficiency of overall system by;

$$\eta_{II} = \frac{\dot{Ex}_{water} + \dot{Ex}_e}{\dot{Ex}_{solar}} \quad (8)$$

3. RESULT AND DISCUSSION

Thermodynamic analyses are carried out taking into account the data of the solar exergy map. As a result of thermodynamic calculations, the energy values, exergy values and the exergy efficiency of selection city are found and these values are given in table 1.

City	$\dot{En}_{solar}$	$\dot{Ex}_{solar}$	$\dot{Ex}_{water}$	η_{II}
Isparta	2775	2592	151.5	0.1291
Bursa	2291	2140	93.44	0.1292
İzmir	2546	2376	93.64	0.1165
Sinop	1782	1665	57.96	0.1448
Ankara	2444	2283	115.8	0.1309
Iğdır	2647	2472	120.3	0.1227
Şanlıurfa	2698	2516	73.84	0.1021

The exergy efficiency of all city are showed in fig. 1.

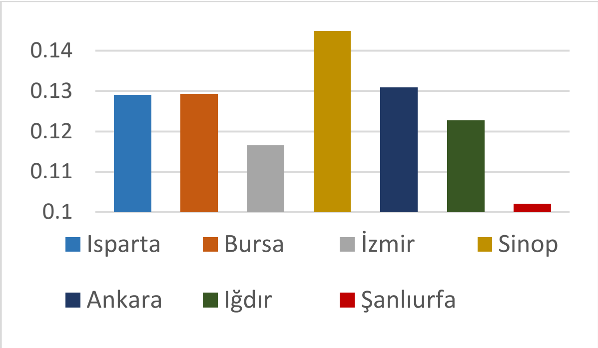

Fig. 1. The exergy efficiency of system

In the following figure 2 (a, b, c, d, e, f, g), the exergy efficiency according to the environmental temperature of the cities and the exergy of output water from the system are shown.

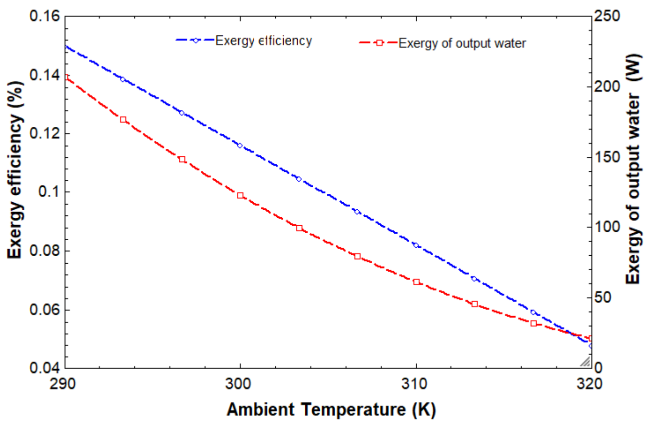

Fig. 2a. Exergy efficiency and the exergy of output water depend on the ambient temperature of the Isparta

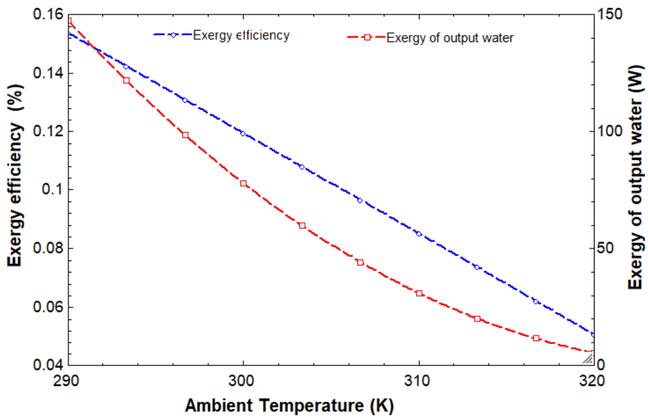

Fig. 2b. Exergy efficiency and the exergy of output water depend on the ambient temperature of the Bursa

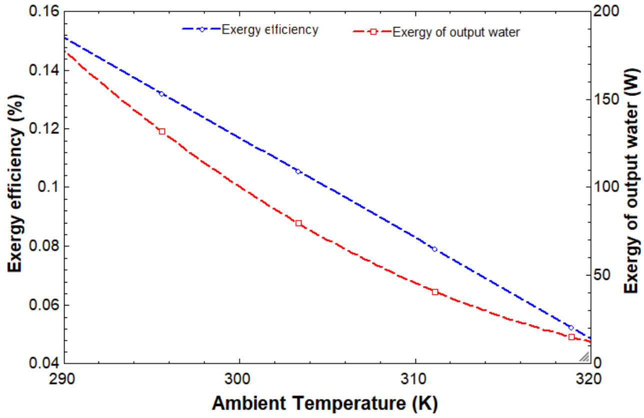

Fig. 2c. Exergy efficiency and the exergy of output water depend on the ambient temperature of the Izmir

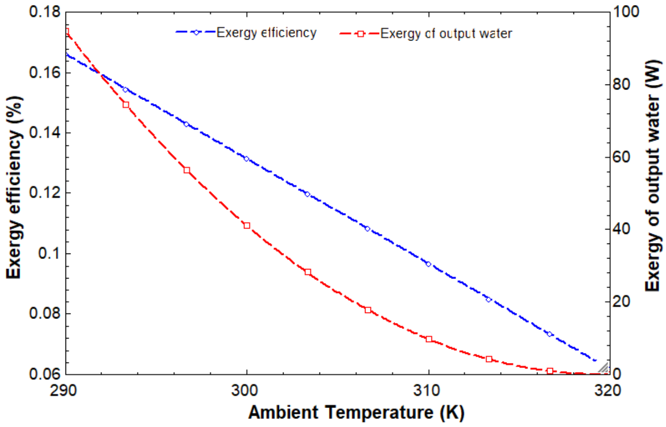

Fig. 2d. Exergy efficiency and the exergy of output water depend on the ambient temperature of the Sinop

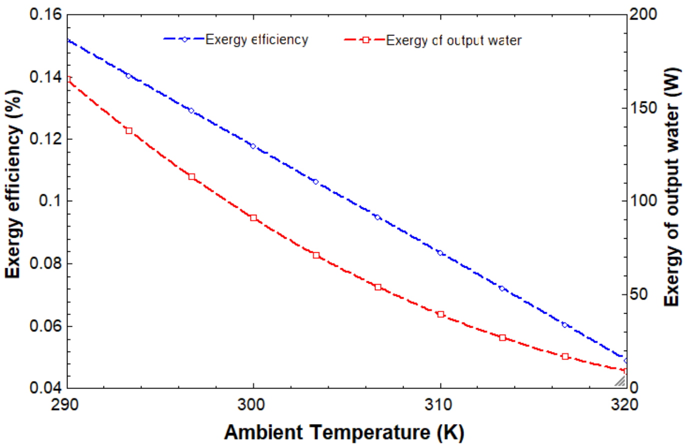

Fig. 2e. Exergy efficiency and the exergy of output water depend on the ambient temperature of the Ankara

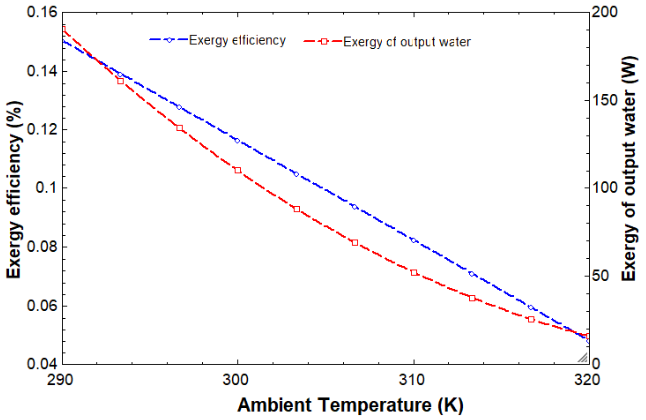

Fig. 2f. Exergy efficiency and the exergy of output water depend on the ambient temperature of the Iğdır

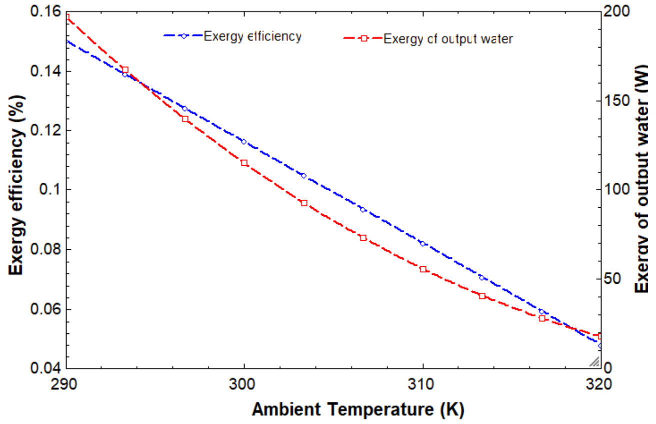

Fig. 2g. Exergy efficiency and the exergy of output water depend on the ambient temperature of the Şanlıurfa

For all cities it has been observed that the environmental temperature (dead state) is a very important effect on exergy production. This is due to the increase in loss of exergy in both the PV panel and the LFR system. In PV systems, the increase in ambient temperature is inversely proportional to the efficiency of PV cells. Therefore, at cities with low ambient temperatures have a higher exergy rate.

Figure 3 (a,b,c,d,e,f,g), shows the solar exergy and the change of exergy in the input-output water depending on the radiation intensity for each city. The solar exergy change for the selected cities is similar, and the change in exergy of the input-output is water varies according to the cities.

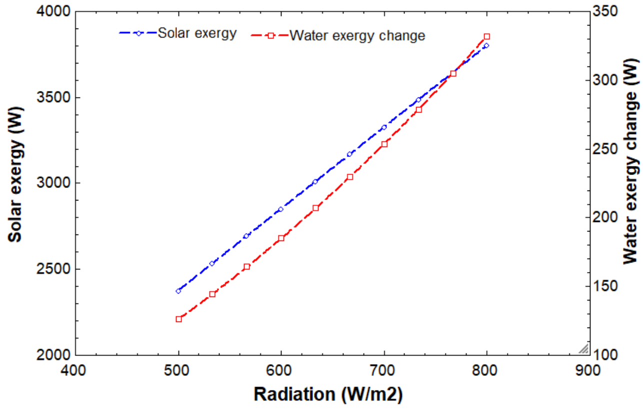

Fig. 2a. Solar exergy and the water exergy change depend on the radiation of the Isparta

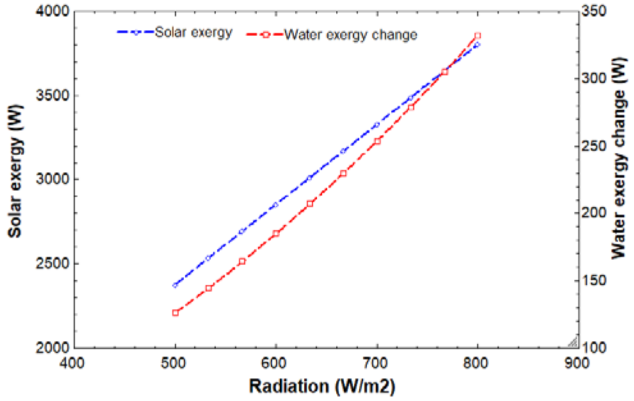

Fig. 2b. Solar exergy and the water exergy change depend on the radiation of the Bursa

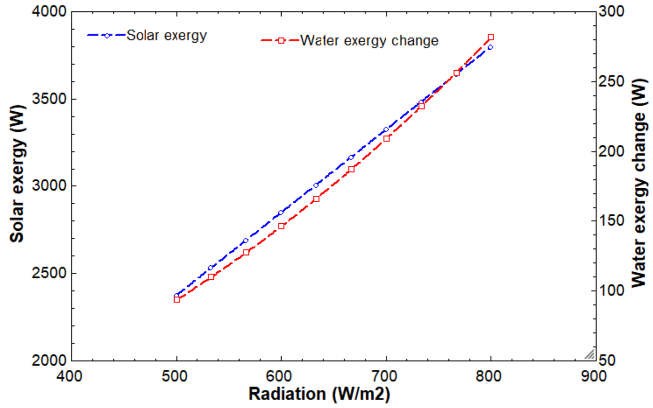

Fig. 2c. Solar exergy and the water exergy change depend on the radiation of the Izmir

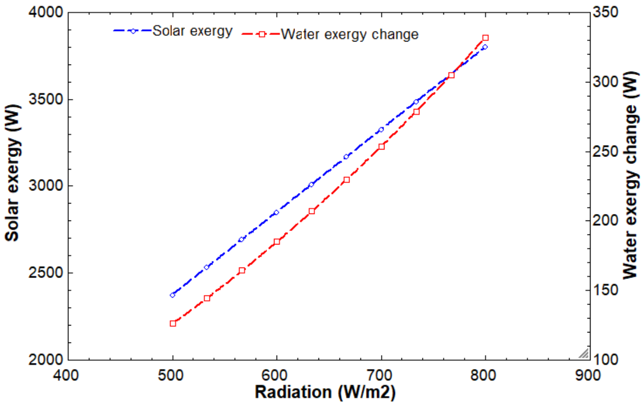

Fig. 2d. Solar exergy and the water exergy change depend on the radiation of the Sinop

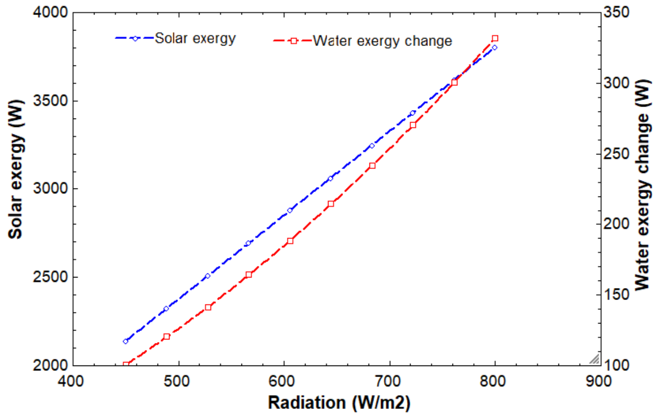

Fig. 2e. Solar exergy and the water exergy change depend on the radiation of the Ankara

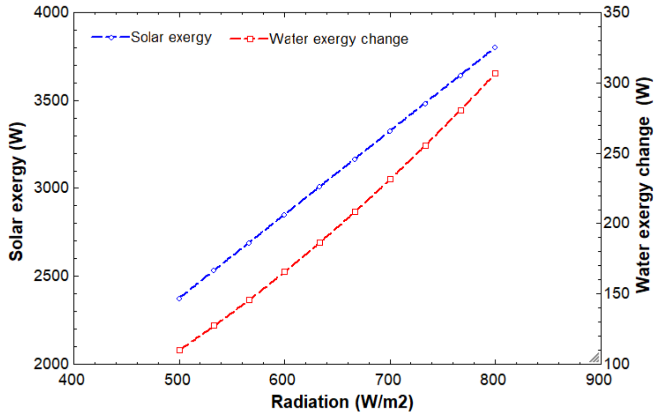

Fig. 2f. Solar exergy and the water exergy change depend on the radiation of the Iğdır

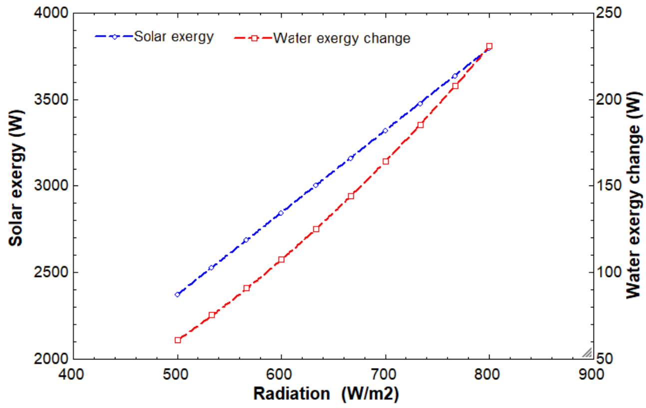

Fig. 2g. Solar exergy and the water exergy change depend on the radiation of the Şanlıurfa

The solar exergy and water exergy change values are graphically shown in figure 2 (a,b,c,d,e,f,g), depending on the different radiation values for each cities. The increase in radiation caused increase in the energy of the circulating fluid in the system.

4. CONCLUSION

In this study solar exergy analysis for Turkey in selected cities for seven regions were done. The aim of this study is to create a map of the solar exergy for Turkey. Both thermal energy and electric energy were calculated for the solar exergy map. LFR systems for thermal energy, PV system for electric energy were investigated. As a result, in this study, it were found that environmental temperature is an important parameter in solar exergy calculations. Such that PV efficiency are found to decrease with increasing temperature of PV cells. Another important parameter on yield is the solar radiation intensity. In this study, solar exergy efficiency of seven different cities, such as Isparta, Bursa, İzmir, Sinop, Ankara, Iğdır and Şanlıurfa was found 0.1291, 0.1292, 0.1165, 0.1448, 0.1309, 0.1227 and 0.1021 respectively.

Nomenclature

I	Solar Radiation (W/m^2)
LFR	Linear Fresnel Reflector
A_{ref}	Reflector Area (m^2)
A_n	Reflector Number
A_{rec}	Receiver Area (m^2)
A_{gs}	Glass Cover Area (m^2)

T_{air} Ambient Temperature (K)
T_s Sun Temperature (K)
T_{surf} Surface Temperature (K)
T_{sky} Sky Temperature (K)
T_{in} Water input Temperature (K)
T_{out} Water output Temperature (K)
E_n Energy (W)
E_x Exergy (W)
$\dot{Ex}_e$ Electrical Power Output (W)
FF Fill Factory
V_{oc} Open Circuit Voltage (V)
I_{sc} Short Circuit Current (A)
$\dot{m}$ Mass Flow (kg/s)

Greek Letters

η Exergy Efficiency (%)
σ Stefan-Boltzmann Constant (W/m^2K^4)
ν Kinematic Viscosity (m^2/s)
ρ_{mir} Reflectance of the mirror
ε_{rec} Emissivity of the Receiver

References

[1] Atkins M.J., Walmsley M.R.W., Morrison A.S., (2010). Integration of solar thermal for improved energy efficiency in low-temperature- pinch industrial processes, Energy, vol 35, pp 1867-1873.

[2] Yakut M.Z., Karabuga A., Kabul A., Selbas R., Design, Energy end exergy analyses of linear Fresnel reflector, Exergetic, energetic and enviromental dimensions. 1th edition, Book chapter, 2018, 523 – 532.

[3] Coskun C., Oktay Z., Dincer I., (2011). Estimation of monthly solar radiation distribution for solar energy system analysis, Energy, vol 36, pp 1319-1323.

[4] Zhang H.,L., Baeyens J., Degrève J, Cacères G., Concentrated solar power plants: review and design methodology, Renewable and sustainable energy review, 22, 2013, 466 – 481.

[5] Yakut M.Z., Karabuğa A., Selbaş R., (2016). Semi-Transparent Building Integrated Photovoltaics: Energy and Daylight, 2th International Conference Tourism Vs Heritage, Proceeding, pp 25-33.Tiwari G.N., Solar energy: Fundamentals, design, modelling and applications. Alpha science international, 2002.

[6] Kalogirou S.A., Solar Energy Engineering: Processes and Systems, Academic Press, Book, 2009.

[7] Zhang H.,L., Baeyens J., Degrève J, Cacères G., Concentrated solar power plants: review and design methodology, Renewable and sustainable energy review, 22, 2013, 466 – 481.

[8] Dincer I., and Acar C., Potential energy solutions for better sustainability, Exergetic, energetic and enviromental dimensions. 1th edition, Book chapter, 2018, 3-37.

[9] Navarro J.P.J., Uhlein A., Mapping regional energy interests for S3P-Energy, JRC Science for Policy Report, European Commission, 2016.

[10] Joshi A.S., Dincer I., Reddy B.V., Development of new solar exergy maps, International Journal of Energy Research, 33, 709-718, 2009.

[11] Arslanoglu N., Empirical modelling of solar radiation exergy for Turkey, Applied Thermal Engineering, 108, 1033-1040, 2016.

[12] Schibuola L., Scarpa M., Tambani C., Calculation procedure to improve the assessment of photovoltaic generation in solar maps, Energy Procedia, 122, 475-480, 2017.